8 Paving Troubleshooting

Problems Observed of the Mixture in the Trucks

Free Asphalt on Mix
Free Dust on Mix
Large Aggregate Uncoated
Mixture Not Uniform
Mixture Fat on One Side
Mixture Flattens
Mixture Burned
Mixture Brown or Gray
Mixture Too Fat
Mixture Smokes
Mixture Steams
Mixture Appears Dull

Problems Observed During Paving

Bleeding
Transverse Joints – Improper Elevation Across Joint
Transverse Joints – Rough Uneven Joint
Screed Marks
Surface Texture Fluctuation
Tearing of Mat – Full Width
Tearing of Mat – Center
Tearing of Mat – Edge
Thickness and Mat Quality Variations
Wavy Surface – Long Waves
Wavy Surface – Ripples, Short Waves

Problems Observed During Compaction

Checking Under Roller
Mat Shoving Ahead of Roller
Roller Marks
Unsatisfactory Compaction

CHAPTER EIGHT:
PAVING TROUBLESHOOTING

Long-term pavement performance is the result of the smoothness and mat quality of the HMA mixture. Smoothness affects the transportation costs of the road user to include vehicle maintenance coasts, fuel consumption, speed, passenger comfort, safety, and vehicle noise. Poor mat quality also affects the pavement performance and may be caused by cracks, segregation, poor joints, and other defects. Furthermore, low density may cause the mix to deform, make the mix more susceptible to moisture, prematurely harden the asphalt, decrease the fatigue resistance, or reduce the structural strength of the pavement.

This chapter will discuss the problems that affect the smoothness and quality of the pavement mat and the possible solutions for correcting these deficiencies. Problems may be detected by observing the mixture in the truck or Material Transfer Vehicle (MTV) during the transfer of the mixture to the paver, by observing the mixture after the paving operations, and by observing the mixture during the compaction process.

PROBLEMS OBSERVED OF THE MIXTURE IN THE TRUCKS

As the HMA is transferred to the paver from the truck or MTV, the operator should observe the mixture for any obvious problems. Problems may be caused by the mixture materials or operations of the plant. The following discussion lists the more common problems observed of the mixture in the trucks or MTV, the type of plant associated with the problem, and the causes of the problems.

FREE ASPHALT ON MIX

Batch and Drum Plants

1. Too much asphalt
2. Faulty distribution of asphalt to aggregates

Batch Plant

1. Aggregate scales out of adjustment
2. Improper weighing
3. Asphalt scales out of adjustment
4. Undersize or oversize batch
5. Improperly set or worn paddles

Drum Plant

1. Asphalt meter out of adjustment
2. Asphalt and aggregate feed not synchronized

FREE DUST ON MIX

Batch Plant

1. Improper weighing sequence
2. Faulty dump gate

LARGE AGGREGATE UNCOATED

Batch and Drum Plants

1. Insufficient asphalt
2. Faulty distribution of asphalt to aggregates
3. Irregular plant operation

Batch Plant

1. Asphalt scales out of adjustment
2. Undersize or oversize batch
3. Mixing time not proper
4. Improperly set or worn paddles

Drum Plant

1. Asphalt meter out of adjustment
2. Asphalt and aggregate feed not synchronized

MIXTURE NOT UNIFORM (FIGURE 8-1)

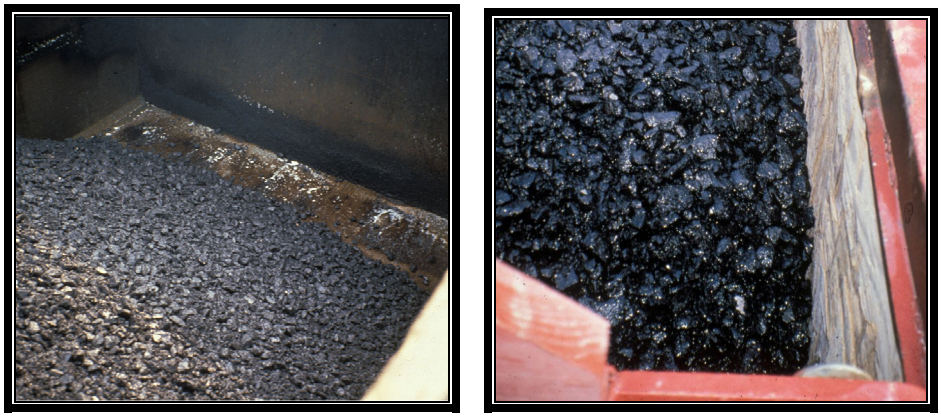

Figure 8-1. End of Truck Segregation

Batch and Drum Plants

1. Leaky Bins
2. Segregation of aggregates in bins
3. Carryover in bins due to overloading screens
4. Insufficient aggregates in hot bins
5. Faulty distribution of asphalt to aggregates
6. Irregular plant operation

Batch Plant

1. Faulty screen operation
2. Bin overflows not functioning
3. Aggregate scales out of adjustment
4. Improper weighing
5. Feed of mineral filler not uniform
6. Improper weighing sequence
7. Asphalt scales out of adjustment
8. Mixing time not proper
9. Improperly set or worn paddles
10. Faulty dump gate
11. Occasional dust shakedown in bins

Drum Plant

1. Asphalt meter out of adjustment
2. Irregular plant operation

MIXTURE FAT ON ONE SIDE

Batch and Drum Plants

1. Faulty distribution of asphalt to aggregates
2. Irregular plant operation

Batch Plant

1. Improper weighing
2. Undersize or oversize batch
3. Mixing time not proper
4. Improperly set or worn paddles

MIXTURE FLATTENS

Batch and Drum Plants

1. Too much asphalt
2. Faulty distribution of asphalt to aggregates
3. Irregular plant operation

Batch Plant

1. Aggregate scales out of adjustment
2. Undersize or oversize batch

Drum Plant

1. Asphalt meter out of adjustment
2. Asphalt and aggregate feed not synchronized

MIXTURE BURNED

Batch and Drum Plants

1. Aggregate feed gates not properly set
2. Improper dryer operation
3. Temperature indicator out of adjustment
4. Aggregate temperature too high
5. Irregular plant operation

MIXTURE BROWN OR GRAY

Batch and Drum Plants

1. Aggregates too wet
2. Over-rated dryer capacity
3. Dryer set too steep
4. Improper dryer operation
5. Temperature indicator out of adjustment
6. Insufficient asphalt
7. Irregular plant operation

Batch Plant

1. Faulty screen operation

Drum Plant

1. Asphalt meter out of adjustment
2. Asphalt and aggregate feed not synchronized

MIXTURE TOO FAT

Batch and Drum Plants

1. Insufficient aggregates in hot bins
2. Too much asphalt
3. Faulty distribution of asphalt to aggregates
4. Irregular plant operation

Batch Plant

1. Aggregate scales out of adjustment
2. Improper weighing
3. Feed of mineral filler not uniform
4. Asphalt scales out of adjustment
5. Undersize or oversize batch

Drum Plant

1. Asphalt meter out of adjustment
2. Asphalt and aggregate feed not synchronized

MIXTURE SMOKES

Batch and Drum Plants

1. Improper dryer operation
2. Temperature indicator out of adjustment
3. Aggregate temperature too high
4. Irregular plant operation

MIXTURE STEAMS

Batch and Drum Plants

1. Aggregates too wet
2. Over-rated dryer capacity
3. Dryer set too steep
4. Improper dryer operation
5. Temperature indicator out of adjustment
6. Irregular plant operation

MIXTURE APPEARS DULL

Batch and Drum Plants

1. Improper dryer operation
2. Temperature indicator out of adjustment
3. Aggregate temperature too high

PROBLEMS OBSERVED DURING PAVING

During the paving operations, the paving crew should observe the mixture behind the screed prior to compaction for obvious problems. Problems may be caused by mix designs, plant operations, existing pavement conditions, or operations of the paver. The following discussion lists the more common problems, the probable causes, and possible solutions.

BLEEDING (FIGURE 8-2)

Figure 8-2. Bleeding

Probable Cause-Possible Solution

1. Prime or tack coat too heavy (Figure 8-3)
    a. Use correct prime or tack coat application rates

Figure 8-3. Tack Too Heavy

2. Poor prime penetration
    a. If granular base is too moist, allow drying period or re-work base material
3. Segregation of HMA
    a. Can be due to many factors including materials handling, mix gradation, operation and condition of storage bins, paver operations, etc.
4. Moisture

TRANSVERSE JOINTS – IMPROPER ELEVATION ACROSS JOINT

Probable Cause-Possible Solution

1. Differential compaction
    a. Set screed on blocks
    b. Allow for compaction of about ¼ in. per 1 in. layer thickness
2. Poor joint preparation
    a. Remove tapered area from previous paving
    b. Prepare well-defined vertical face

TRANSVERSE JOINTS – ROUGH UNEVEN JOINT

Probable Cause-Possible Solution

1. Poor compaction technique
    a. Roll joint transversely
    b. Use correct compaction technique
2. Poor raking technique or excessive raking (Figure 8-4)
    a. Minimize raking
    b. Trim and remove any excess from cold side of joint

Figure 8-4. Poor Raking at Joint

3. Segregation of HMA at mat edge
    a. Can be due to many factors including materials handling, mix gradation, operation and condition of storage bins, paver operations, etc.

SCREED MARKS (FIGURE 8-5)

Figure 8-5. Screed Marks

Probable Cause – Possible Solution

1. Thickness control screws in poor mechanical condition
    a. Replace control screws
2. Variable material level in front of screed
    a. Adjust hopper gates and/or feed conveyor/spreading screw speeds
    b. Adjust depth sensor
3. Improper operation of paver
    a. Use proper paving procedures
    b. Release brakes on truck
4. Truck bumps paver or is not square with paver (Figure 8-6)
    a. Allow paver to approach truck
    b. Make sure all rear wheels of truck are in contact with roller bar on paver

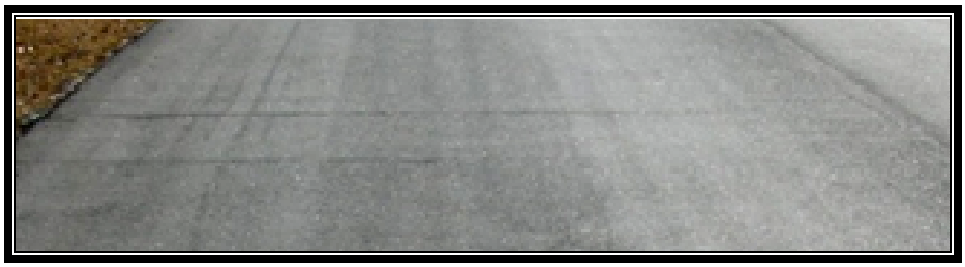

Figure 8-6. Marks Due to Truck Bumping Paver

5. Over-sensitive automatic controls or tender mix
    a. Check mix proportions and aggregate quality
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check and correct if moisture in mix
    d. Check asphalt grade and temperature-viscosity characteristics
6. Excessive play in screed mechanical connection
    a. See operation and maintenance manual

SURFACE TEXTURE FLUCTUATION

Probable Cause – Possible Solution

1. Too much raking and sanding behind machine
    a. Use proper raking procedure
2. Variable HMA quality
    a. Check mix proportions and sampling procedures
    b. Correct at mixing plant
3. Poor temperature control of HMA
    a. Correct temperature at mixing plant according to asphalt temperature-viscosity characteristics
    b. Cover load during hauling and waiting
4. Poor asphalt quality
    a. Check for asphalt overheating
    b. Check with asphalt supplier
    c. Test asphalt properties
5. Segregation of HMA
    a. Could be due to many factors including stockpiling procedures, mix gradation, operation and condition of storage bins, paver operations, etc.
6. Stone size too large for layer thickness
    a. Reduce stone size to maximum of one-half of layer thickness
    b. Revise mix design
7. Worn screed plates - stone degradation
    a. Replace screed plates
    b. Check stone quality and rolling techniques
    c. Mix too coarse or too cold
8. Variable forward speed of paver
    a. Maintain constant forward speed

TEARING OF MAT – FULL WIDTH (FIGURE 8-7)

Figure 8-7. Mat Tearing Full Width

Probable Cause – Possible Solution

1. Stone size too large for layer thickness
    a. Reduce stone size to a maximum of half of the layer thickness
    b. Revise mix design
2. Tender Mix
    a. Check mix proportions
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check and correct if moisture in mix
    d. Check asphalt grade and temperature-viscosity characteristics
3. Forward speed of paver too fast
    a. Reduce paver speed
4. Worn out screed plate
    a. Replace screed plate
5. Mix too dry or too harsh
    a. Check if mix may be too coarse or aggregates too dirty
    b. Increase VMA and asphalt content
    c. Consider addition of natural sand

6. Mix temperature too low
    a. Increase mix temperature at plant according to temperature-viscosity characteristics or in accordance with asphalt supplier recommendations
    b. Cover load during hauling and waiting
7. Rapid cooling of mat surface
    a. Check air temperature and wind chill effects
    b. Increase number of rollers
    c. Reduce forward speed of paver
8. Cold paver speed
    a. Heat screed

TEARING OF MAT – CENTER (FIGURE 8-8)

Figure 8-8. Tearing of Mat – Center

Probable Cause – Possible Solution

1. Not enough lead crown
    a. Increase lead crown
2. Mix temperature too low
    a. Increase mix temperature at plant according to temperature-viscosity characteristics or in accordance with asphalt supplier recommendations
    b. Cover load during hauling and waiting
3. Worn screed plate
    a. Replace screed plate

4. Incorrect feeder gate setting
    a. Correct feeder gate setting
5. Kicker screws worn out or mounted incorrectly
    a. Replace or adjust kicker screws
6. Segregation of HMA at centerline (Figure 8-9)
    a. Could be due to many factors including stockpiling procedures, mix gradation, operation and condition of storage bins, paver operations, etc.

Figure 8-9. Centerline Segregation

TEARING OF MAT – EDGE

Probable Cause – Possible Solution

1. Mix temperature too low
    a. Increase mix temperature at plant according to temperature-viscosity characteristics or in accordance with asphalt supplier recommendations
    b. Cover load during hauling and waiting
2. End plates not square
    a. Check position of end plates

3. Too much lead crown in screed
    a. Reduce lead crown
    b. Check for improper strike-off position
4. Worn screed plate
    a. Replace screed plate
5. Excessive overlap
    a. Ensure no more than 3 in. overlap
6. Cold Screed
    a. Heat screed
7. Incorrect feeder gate setting
    a. Correct feeder gate setting
8. Screed extensions installed incorrectly
    a. Refer to manufacturer's manual for correct installation
9. Segregation of HMA at mat edge
    a. Could be due to many factors including stockpiling procedures, mix gradation, operation and condition of storage bins, paver operations, etc.

THICKNESS AND MAT QUALITY VARIATIONS

Probable Cause – Possible Solution

1. Poor control of material in front of screed
    a. Adjust hopper gates and/or conveyer/spreading screw speed
    b. Check location and operation of feed sensors to ensure consistent auger and feeder spread
2. Screed pull point set at improper height
    a. Raise screed pull point. Check line of pull (draw line from bottom of tow point cylinder to pivot point of screed) and check that this line is parallel with grade
3. Improper operation of paver
    a. Use proper procedures
4. Out-of specification HMA
    a. Check mix proportions and sampling procedures
    b. Correct at mixing facility
5. Poor temperature control
    a. Correct at mix plant according to temperature-viscosity characteristics or in accordance with asphalt supplier recommendations
    b. Cover load during hauling and waiting
    c. Consider remixing material at paving site if temperature differential is more than 25°F across width of mat behind screed

6. Poor asphalt content control
    a. Evaluate sampling and testing procedures
    b. Use Quality Control charts
    c. Check asphalt meters or weigh buckets
    d. Check belt scales
7. Over-controlling of screed
    a. Adjust automatic controls to more closely meet mat thickness
    b. Make sure automatics are adjusted to correct sensitivity as recommended by manufacturer
    c. Check for smooth uniform movement of tow point cylinders
8. Unstable or tender HMA (Figure 8-10)
    a. Check mix proportions and aggregate quality
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check and correct if moisture in mix
    d. Check asphalt grade and temperature-viscosity characteristics

Figure 8-10. Unstable HMA

9. Poorly graded surface of base
    a. Use proper base preparation
    b. Use stringline or laser reference for grade control
    c. Use longer averaging ski or an inline-averaging ski if grade is unacceptable outside of paver end gates
10. Hydraulic screed lift is not released
    a. Release hydraulics
    b. Check for improper or impaired operation of hydraulics

11. Yielding underlayer – granular bases (Figure 8-11)
    a. Improve or modify
    b. Check density
    c. Do not lay HMA over a saturated base
    d. Check drainage

Figure 8-11. Yielding Granular Base

12. Yielding underlayer – overlays
    a. Cut out and patch weak areas
    b. Maintain constant forward speed
    c. Match paver speed to plant output
13. Material on existing pavement (Figure 8-12)

Figure 8-12. Dumped Material on Pavement

WAVY SURFACE – LONG WAVES

Probable Cause – Possible Solution

1. Poor temperature control of HMA
    a. Correct temperature at mixing plant according to asphalt temperature-viscosity characteristics
    b. Cover load during hauling and waiting
2. Over-controlling screed
    a. Adjust automatics to match mat thickness
3. Brakes set on truck
    a. Release brakes
4. Hydraulic screed lift not released
    a. Release hydraulics
    b. Check for improper or impaired operation of hydraulics
5. Variable material level in front of screed (Figure 8-13)
    a. Adjust hopper gates and/or feed conveyor/spreading screw speed
    b. Adjust depth sensor

Figure 8-13. Auger Material Too Low

WAVY SURFACE – RIPPLES, SHORT WAVES (FIGURE 8-14)

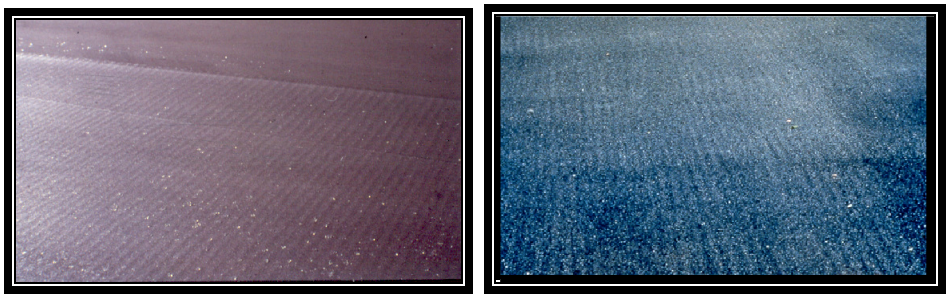

Figure 8-14. Wavy Surface – Short Waves

Probable Cause – Possible Solution

1. Variable HMA quality
    a. Maintain job mix within specification limits
2. Unstable or tender HMA
    a. Check mix proportions and aggregate quality
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check moisture content of mix
    d. Check asphalt grade and temperature-viscosity characteristics
3. Loading screws too heavy
    a. Adjust hopper gates, and/or feed conveyor/spreading screw speeds
    b. Adjust depth sensor
4. Too much slack in roller drives
    a. Adjust roller drives
5. Poor temperature control of HMA
    a. Control temperature at mixing plant according to asphalt temperature-viscosity characteristics
    b. Cover load during hauling or waiting
6. Screed pull point too low on tractor
    a. Raise pull points
7. Improper operation of paver
    a. Use proper paving procedures

PROBLEMS OBSERVED DURING COMPACTION

CHECKING UNDER ROLLER (FIGURE. 8-15)

Figure 8-15. Checking Under Roller

Probable Cause – Possible Solution

1. Yielding underlayer – granular bases
    a. Check density
    b. Do not lay HMA over a saturated base
    c. Check drainage
2. Yielding underlayer – overlays
    a. Cut out and patch weak areas
3. Tender mix
    a. Check mix proportions and aggregate quality
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check and correct if moisture is in mix
    d. Check asphalt grade and temperature-viscosity characteristics
    e. Change position of roller in the pattern (vibratory to intermediate, static to breakdown, etc.)
4. Poor asphalt quality
    a. Check that asphalt has not been overheated or contaminated with harder grade
    b. Check with supplier
    c. Test asphalt properties

5. Asphalt content too low
    a. Revise mix design
    b. Increase asphalt content
    c. If necessary, increase VMA
6. Excess filler and/or fine aggregate
    a. Reduce and revise mix design
    b. Check fines metering system at plant
7. Segregation of HMA
    a. Could be due to many factors including stockpiling procedures, mix gradation, operation and condition of storage bins, paver operations, etc.
8. Too much rolling
    a. Use correct rolling procedure
9. Mix too hot
    a. Correct at mixing facility
    b. Delay rolling
    c. Reduce compaction temperatures according to aggregate properties and viscosity of asphalt
    d. Assure large drive drum is in the direction of forward travel
10. Rapid cooling of mat surface
    a. Check air temperature and wind chill effects
    b. Increase lift thickness to reduce heat loss, if possible
    c. Increase number of rollers
    d. Reduce forward speed of paver

MAT SHOVING AHEAD OF ROLLER (FIGURE 8-16)

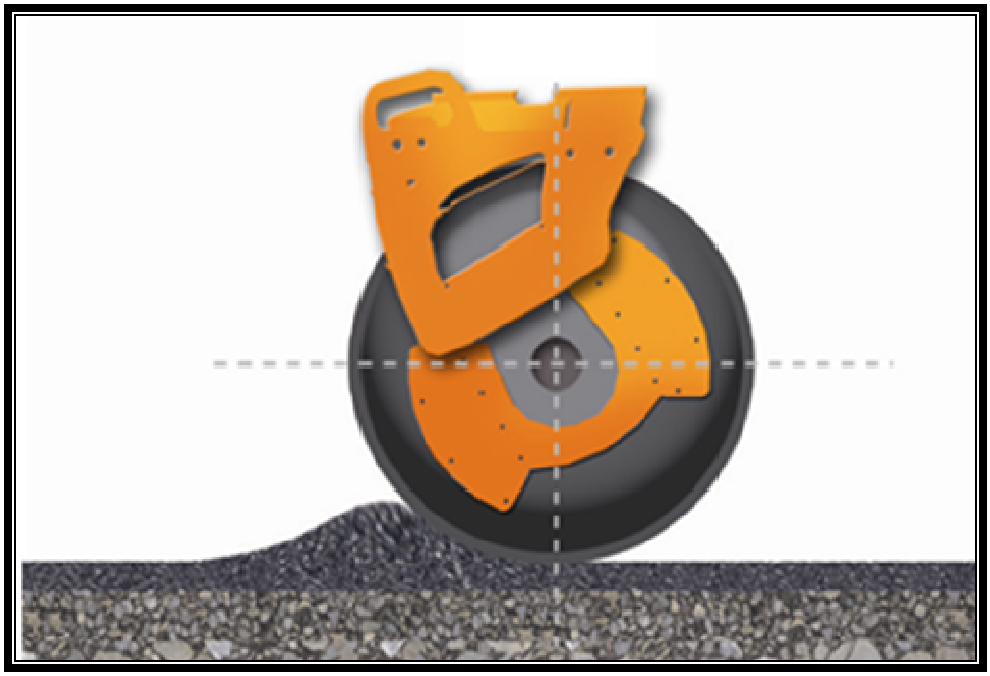

Figure 8-16. Mat Shoving Ahead of Roller

Probable Cause – Possible Solution

1. Roller reversing or turning too abruptly
    a. Gradually slow and reverse
    b. Make wide radius turns
2. Tire pressure of rubber tire roller too high
    a. Reduce tire pressures
3. Roller on fresh surface too soon
    a. Delay rolling
    b. Reduce compaction temperatures according to aggregate properties and viscosity of asphalt
4. Asphalt content too high
    a. Revise mix design
    b. If necessary, reduce VMA
5. Yielding underlayer – granular bases
    a. Check density
    b. Do not lay HMA over a saturated base
    c. Check drainage
6. Yielding underlayer – overlays
    a. Cut out and patch weak area
7. Aggregate gradation
    a. Check mix proportions
    b. Reduce fines and uncrushed aggregates
8. Moisture in mix
    a. Reduce moisture in material stockpiles, if possible
    b. Increase proper drying time
9. Dusty or dirty base
    a. Clean with motorized broom
10. Mix temperature too high
    a. Reduce at mixing facility according to asphalt temperature-viscosity characteristics or in accordance with asphalt supplier's recommendations
11. Un-combusted fuel in mix
    a. Ensure fuel is at correct viscosity for burning
    b. Ensure that there is not too little or too much excess air
    c. Inspect and, if necessary, adjust burner
    d. Check fuel quality
12. Poor asphalt cement quality
    a. Check asphalt temperature for overheating
    b. Test asphalt properties
13. Moisture accumulation due to condensation
    a. Check mix design temperature and storage time in surge bins
14. Tender zone
    a. Check temperature ranges for tender zone
    b. Compact above or below tender zone
15. Excessive mat thickness relative to aggregate size
    a. Reduce individual lift thicknesses, if possible

16. Incorrect amplitude or frequency settings
    a. Adjust according to actual site conditions
17. Prime or tack coat too heavy or too light (Figure 8-17)
    a. Use correct application rates
    b. Check sprayer calibration

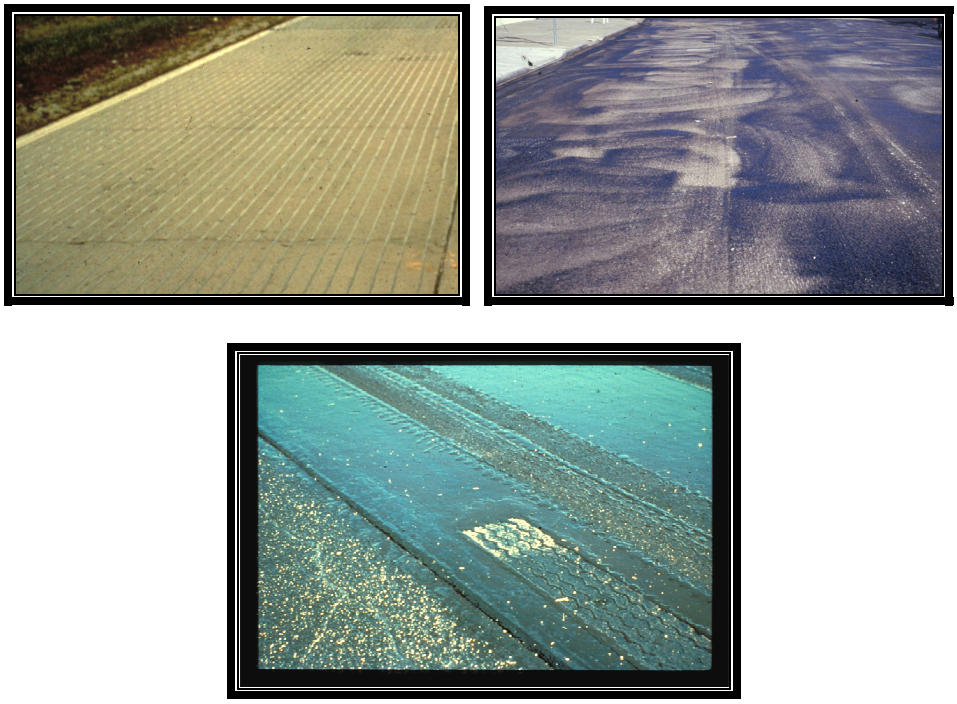

Figure 8-17. Incorrect Tack Coats

ROLLER MARKS

Probable Cause – Possible Solution

1. Tender mix
    a. Check mix proportions and aggregate quality
    b. Revise design if excess sand, low filler content, or high asphalt content
    c. Check and correct if excess moisture in mix
    d. Check asphalt grade and temperature-viscosity characteristics
    e. Check temperature ranges for tender zone.
    f. Compact above or below tender zone
2. Bump/indentation due to reversing or turning roller too abruptly
    a. Gradually slow and reverse
    b. Make wide radius turns especially for vibratory rollers
    c. Shut off vibration of vibratory roller before reaching the end of the rolling zone
    d. Run straight in and out on successive passes and not make wide radius turns on hot HMA
    e. Stop rollers at an angle (Figure 8-18)

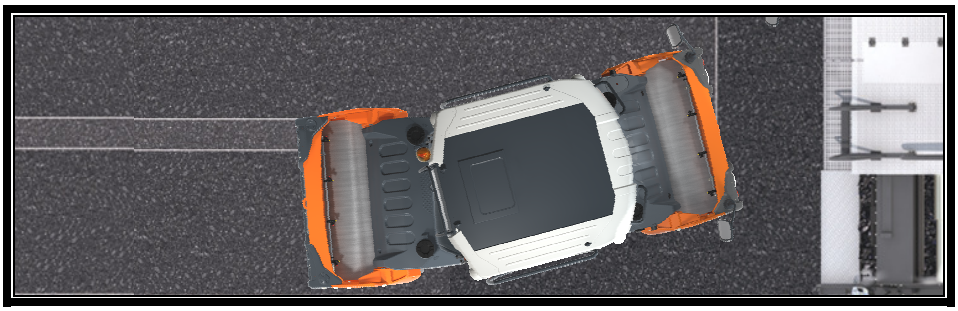

Figure 8-18. Stopping Roller at an Angle

3. Bump/indentation caused by faulty drive system
    a. Check complete drive system of roller including hydrostatic pumps and motors
4. Edge marks from weight shift when rolling superelevated curve
    a. Roll uphill. Start at bottom of superelevation and roll into elevation, picking up the overlap on successive passes
5. Rough, uneven pavement due to material pick-up on pneumatic, rollers
    a. Allow mix to cool and tires to reach mat temperature
6. Rough, uneven pavement due to material pick-up on steel or vibratory steel rollers
    a. Ensure water spray nozzles operating and the water tank is full
    b. Properly adjust rubber scrappers, cocoa mats, and steel scrapers
7. Bump/indentation from parked roller
    a. Don't park roller on mat or vibrate drum when roller is stationary
    b. Park roller on cool compacted HMA transverse to the direction of paving
8. Bump/indentation from vibratory roller
    a. Reduce roller passes
    b. Reduce amplitude
    c. Do not vibrate on cold HMA surface
9. Flat spot or dent on roller drum
    a. Replace roller
10. Gap too wide between halve or split drum
    a. Keep roller drums and tires clean
    b. Ensure scraper and mats are properly adjusted
11. Tender zone
    a. Stay out of tender zone
    b. Adjust rolling procedures

UNSATISFACTORY COMPACTION

Probable Cause – Possible Solution

1. Poor temperature control of HMA (mix temperature too cold or too hot)
    a. Correct temperature at plant according to temperature-viscosity characteristics or in accordance with asphalt supplier's recommendations
    b. Cover load during hauling and waiting
2. Poor asphalt quality
    a. Check that asphalt has not been overheated
    b. Check with supplier
    c. Test asphalt properties
3. Asphalt content too low
    a. Revise mix design to increase asphalt content, if possible
4. Hydraulic screed lift not released
    a. Release hydraulics
    b. Check for proper or impaired operation of hydraulics
5. Rapid cooling of mat surface
    a. Check air temperature and wind chill effects using temperature sensors
    b. Increase lift thickness, if possible
    c. Run two breakdown rollers in echelon
    d. Reduce forward speed of paver
6. Mix too dry or too harsh
    a. Revise mix design to increase VMA and asphalt content
    b. Consider adding natural sand
    c. Check fines return system at plant
7. Rolling too fast
    a. Slow down rollers
    b. For vibratory rollers, maintain frequency and speed that results in a minimum of 10 impacts per foot
8. Roller too light, compactive effort too low
    a. Use heavier roller
    b. For static rollers, increase roller ballast
    c. For vibratory rollers, set amplitude to match lift thickness and type of material
9. Inadequate rolling compaction or too few rollers/improper rolling pattern
    a. Establish test strip to determine type and number of rollers required to maintain specified density and smoothness. And maintain production capability of plant, trucking, and paver
    b. Slow paver to maintain proper rolling pattern
10. Out-of-specification HMA
    a. Check that mix proportions and sampling procedures are correct at mixing facility

11. Segregation of HMA
    a. Could be due to many factors (Figure 8-19)

Figure 8-19. End of Truck Segregation

11. Yielding underlayer – granular bases
    a. Check density
    b. Do not lay HMA over a saturated base
    c. Check drainage
12. Yielding underlayer – overlays
    a. Cut out and patch weak area
13. Rolling zones
    a. Work roller as close to the paver as possible
    b. Determine mat surface temperatures for rolling zones
    c. Maintain effective rollers in zones
14. Vibrator not operating
    a. Check for electric of hydraulic system malfunction
15. Improper frequency (VPM) and amplitude settings on vibratory roller
    a. Set frequency and amplitude in relation to lift thickness, material, travel speed, and density requirement